MULTI-CONDUCTOR PLUG AND SOCKET APPARATUS

Field of the Invention

This invention relates to electrical connections, and more particularly electrical connections that are electrically activated only when such connections are fully and appropriately engaged. The invention is specifically useful when the electrical connections are in the form of coaxial, fixed diameter, multi-contact mating plug and socket means.

Background of the Invention and Description of the Prior Art

In certain applications it is necessary to connect two active (powered) electrical circuits together, typically by using a coaxial plug and socket connectors, each having mating diameters and with multiple circumferential mating spaced apart electrical contacts.

The procedure of engaging a multiple coaxial plug within a coaxial socket aperture so as to form the electrical connection with the multiple electrical contacts thereon will cause many of the contacts in the plug to "wipe" past those of the socket during insertion, generally in an electrically inappropriate manner, and may damage the electronic circuits associated with such contacts before the contacts are each fully and appropriately engaged with the corresponding electrical contact. In addition, a further problem arises in that the preferred method of making such electrical connections is typically to insert by rotationally screwing one tubular housing containing the plug into a

similar tubular housing containing the socket. The environment in which this occurs could also be hazardous – for instance, on the floor of an oil-drilling rig where flammable gases may be present. In such circumstances it is advisable to make certain that no potentially live electrical contacts are capable of causing a spark or thermal effect that could ignite flammable gas, dust or vapor during rotatable insertion of the plug into the socket.

Still further problems exist with the hazardous environment in which such plus-socket connectors may be exposed. For example, drilling strings used in the oil industry require insertion therein of electronic monitoring and transmitting devices to allow drill operators to monitor various drilling parameters at the base of the well bore during drilling operations. Electronic devices which fit within the inner diameter of drill pipe of a drill string are typically cylindrical devices consisting of sensors, telemetry apparatus and batteries or power supplies, that together on average are less than 2 inches in diameter, and when connected can be 30 feet long. Such devices typically comprise specific pressure housings that require mechanical and electrical interconnections (contacts). These connection points are particularly vulnerable to severe shock and vibration, bending, compression and tension, high pressures and high fluid flow rates in the very harsh downhole-drilling environment.

Various methods have been developed and used in the industry to join, both mechanically and electrically, components of such electronic devices together in order to cope with the conditions of a drilling environment. The majority of these devices comprise a multi-contact plug and socket that cannot

be rotated one into the other. Such connectors are firstly joined in a specified fashion and are then typically protected by a mechanical housing able to resist the downhole pressure. Many problems arise from the relatively complicated connection procedures necessary to connect such tool modules together, since not only must the longitudinal positioning of the two components be aligned but also they must be aligned properly in the angular sense relative to each other.

A simplification in the connection process that allows a more robust and reliable connection to exist utilizes a coaxial barrel style plug and socket design. Such design enables the plug to be attached to a housing, the socket attached to a similar housing and the pair are then simply pushed or screwed one into the other. Significant advantages that follow from the use of such a system are that smooth barrel joints are easily implemented, thereby minimizing flow erosion; mechanical complexity is reduced leading to more reliable systems and cost-effective implementations; and tool modules themselves can be housed in larger drill collars, enabling a simplification of the process whereby ‘collar plus tool’ is attached to another ‘collar plus tool’.

One prior art design that is economical, basic and reliable involves a coaxial barrel style plug and socket having a single diameter. Such design would otherwise be the connector system of choice were it not for the following problems, namely, that when fully engaging a single diameter plug and socket many of the contact rings slide past each other. In a connection system of more than two contact rings (and hence more than two electrical lines) that may be

electrically active, there is a danger that misappropriate or unsafe connections may be made thereby damaging associated electronic circuits.

A known prior-art method and configuration to avoid the above problem of "wiping" causing inappropriate electrical connection is to modify the spacing of the contacts on the plug and socket pair such that no more than a single contact is able to make contact with another before engagement. This method, and a plug and socket combination employing such a configuration, is taught in Patent US 6,439,932. The aforesaid method and configuration has the serious disadvantage that in order the ensure no more than one contact connection is allowed at any time prior to full engagement, the inter-contact spacings have to be implemented at increasingly large distances from each other. This leads to a costly, long and unwieldy plug and socket pair, particularly when more than six independent connections have to be made. For instance, a mathematical analysis will show that such a connector is more than twice the length of a normal coaxial connector implemented with uniform spacing.

A plethora of alternative schemes that use switching means that electrically isolate connections until the appropriate electrical connections are fully made and thus avoid the wiping problem are discussed below.

US Patent 6,528,746 shows a non-coaxial connector means that uses a magnet to activate a magnetic flux responsive device (typically a reed switch) that then enables connections to be made.

US Patent 5,048,914 shows a non-coaxial connector that uses an optical transmitter/receiver pair to activate its switches.

US Patent 5,580,261 teaches a means for connecting a single pair of coaxial contacts which relies on the mechanical motion of an internal switch, the switch means ultimately causing a mechanical connection of the contacts. This invention is typical of the class of mechanical movement initiating further connections.

Another class of mechanical switches is the subject of many inventions that rely on solid-state switches (electronic switches) to control further switched connections. US 4,346,419 is an example of this area of prior art. It specifically teaches the use of non-coaxial contacts of differing lengths, a short pair (last to connect) that when connected enables a solid-state switch to pass relatively high current through other longer pairs of longer contacts. Disadvantageously, this design requires the last contact to be continuously supplied with a voltage. Accordingly, despite low "trigger" voltages being used, such configuration is nonetheless unsatisfactory in explosive environments due to the possibility of initiating an explosion.

Typical of modern coaxial connectors is the invention as shown in Patent US 6,435,917. This teaches an improved manner of maintaining a reliable connection specifically related to socket contacts. However, such design provides no protection against inappropriate connections being made when engaging plug into socket.

US 5,984,687 and US 5,409,403 are typical of rotatable coaxial connector patents. These examples teach the use in specific circumstances of placing each successive contact on a successively increasing diameter. The essential advantages of this class of design are that all contacts are made only when plug and socket are essentially fully engaged, and that plug and socket can rotate about a common axis. The disadvantages are that such devices are relatively expensive and usually require a significantly larger diameter implementation than a simple fixed diameter coaxial multi-contact plug and socket, such as is specified in the present invention. Furthermore, there is no means by which such devices alone could safely operate in an explosive or hazardous environment.

In conclusion, the prior art teaches the use of plugs and sockets in rotatable (coaxial) and non-rotatable forms that enable contacts to connect when a fully engaged position between plug and socket is achieved. The determination of this position is implemented via one or more of the following, namely:

contact axial spacing differences;
contact diameter spacing differences;
mechanical movement of a probe enabling contacts to be connected;
optical switch; and,
a magnetic switch.

While these above prior art designs exist, there is a real need, however, for a plug and socket design which combines a number of features, namely:

comparatively small in footprint;

avoids the "wiping" problem;

simple mechanical housing;

can operate in hazardous environments; and

relatively inexpensive relative to some of the prior art designs.

SUMMARY OF THE INVENTION

Our invention enables a multi-contact coaxial plug to be axially inserted into its partner socket while electronic circuits attached to either side of the plug and/or socket are isolated from any harmful electronic misalignment during the engagement procedure. The plug and socket do not require any particular contact spacing and so can be realized in the smallest appropriate volume i.e. small fixed diameter and short fixed contact spacings.

Accordingly, the invention, in one of its broad aspects, contemplates a very simple basic electrical diode attached to the plug, enabling a sensor circuit attached to the socket to activate various solid state switches to protect the socket's attached electronic circuitry and permit electrical supply of power only when the plug and socket combination are fully engaged, and a similar standard electrical diode attached to the socket enabling a similar sensor circuit attached to the plug to activate various solid state switches to protect the plug's attached electronic circuitry also only when the plug and socket combination are fully engaged. The sensor circuits are symmetric and allow the protection means to

activate when either the plug's circuit only is implemented, when the socket's circuit only is implemented, or when both are implemented. A specific embodiment facilitates this activation for both circuits when either or both are electrically powered.

A specific advantage of our invention is that such electrical connections and disconnections can be safely undertaken in hazardous environments.

Specifically, the present invention in one of its broad embodiments comprises a multiconductor plug and socket means;

said plug means having at least three electrically conducting plug contacts thereon, adapted for insertion in socket means;

said socket means having a corresponding number of electrically conductive socket contacts thereon;

a first of said plug contacts electrically coupled to a second of said plug contacts via a plug-side current direction-limiting means ;

a first of said socket contacts electrically coupled to a second of said socket contacts via a socket-side current direction-limiting means;

said first and second plug contacts adapted for electrical communication with said first and second socket contacts only upon proper engagement of said socket means with said plug means; and

circuit isolation means, said circuit isolation means only permitting flow of electrical current through one or more remaining plug-socket contact pairs when current flow through at least one of said plug-side and socket-side current direction-limiting means is detected.

The current direction-limiting device referred to above is typically a diode, but may be any combination of electrical or electronic circuits capable of providing this functionality.

In one refinement of the present invention, the circuit isolation means comprises plug-side circuit isolation means, said plug-side circuit isolation means only permitting flow of electrical current to at least one remaining plug contact when current flow through said socket-side current direction-limiting means is detected.

In an alternative refinement of the present invention, the circuit isolation means comprises socket-side circuit isolation means, said socket-side circuit isolation means only permitting flow of electrical current to at least one remaining plug contact when current flow through said plug-side current direction-limiting means is detected.

In a further refinement of the invention, where circuit isolation means is desired to prevent unintended shorting to electronic circuits on both the plug side and socket side of the electrical connection, the circuit isolation means

comprises both plug side circuit isolation means and socket side circuit isolation means, both functioning as described above.

A timing circuit preferentially forms part of the circuit isolation circuit, and includes a delay from the time of connection between the plug means and socket means during which time electrical connection between the contacts must be fully established. One advantage of a timing circuit is that such a time delay prevents premature or intermittent contact associated with the current direction limiting means (typically a diode) from consequently triggering the establishment of electrical power to one or both of the plug contacts or socket contacts before full engagement of the plug means within socket means has been obtained.

In yet a further broad aspect of the present invention, the present invention comprises an apparatus for establishing electrical connection between a pair of electrical contacts, comprising :

plug means;

socket means;

said plug means having one of said pair of electrical contacts thereon and a further first and second electrical plug contact thereon, said plug means adapted for insertion in said socket means;

said socket means having the other of said pair of electrical contacts thereon, and a further first and second socket contact thereon;

said first of said plug contacts electrically coupled to said second of said plug contacts via a plug-side current direction-limiting means;

said first socket contact electrically coupled to said second of said socket contacts via a socket-side current direction-limiting means;

said first and second plug contacts adapted for electrical communication with said first and second socket contacts only upon proper engagement of said socket means with said plug means; and

circuit isolation means, said circuit isolation means only permitting flow of electrical current through said pair of electrical contacts when current flow is detected through at least one of said plug-side and socket-side current direction-limiting means.

BRIEF DESCRIPTION OF THE DRAWINGS

The following drawings, showing preferred embodiments of the invention, are illustrative only, and for a complete definition of the scope of the invention, reference is to be had to the summary of the invention and the claims.

Figure 1 is a schematic showing a generalized form of the coaxial plug and socket connection of the present invention;

Figure 2 is a more detailed schematic diagram of the isolation circuit for the plug isolating electronic switch circuit shown in Figure 1;

Figure 3 is a more detailed schematic diagram of the isolation circuit for the socket side isolating electronic switch circuit shown in Figure 1;

Figure 4 shows schematically a sensor circuit of the type used in the isolation circuits shown in Figure 1, where both plug and socket have associated circuits and are each electrically powered;

Figure 5 is a sensor circuit similar to that shown in Figure 4, but modified slightly to form an alternate embodiment;

Figure 6 shows schematically a sensor circuit, where only the plug side has associated isolation circuits and is electrically powered;

Figure 7 shows schematically a sensor circuit, where only the socket side has associated circuits and is electrically powered; and,

Figure 8 is a schematic drawing showing a typical plug and socket connector which may be used in the present invention, indicating wiring connections that corresponds to the associated wiring of the respective plug and socket electrical isolation circuits.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

While there are many methods of connecting two electronic circuits together, in one aspect the invention contemplates use of a coaxial plug and socket pair **212** and **226** respectively, as indicated in **Figure 1**, each having a plurality of coaxially situate, concentric electrical contacts **211**, **213** respectively thereon. The advantage of using such a coaxial multi-contact system is that the plug **212** and socket **226** can be housed in tubular containers (not shown) and the containers may be screwed together, thereby engaging the coaxial plug **212** into socket **226**. The mechanical advantage of this method of engagement brings a disadvantage – the majority of the contacts **211**, **213** wipe past each other during insertion of plug **212** into socket **226** before the plug **212** and socket **226** become fully engaged. This may cause damage to attached electronic components if they are activated by some power source. Accordingly, the invention provides for interposing specific isolation circuits **202** and/or **216** to isolate and protect such components during the engagement

process. We accomplish this by connecting plug **212** via wire harness **210** to switching circuit **202**. This circuit **202** isolates a variety of input/output lines (I/O) **200** from I/O lines **208**. A pair of lines is dedicated to use as sensor lines (Sensor Line 1 **280** and Sensor Line 2 **282**) and are attached to contacts **284** and **286** which are preferably but not necessarily at the distal end **207** of plug **212**. Similarly we connect socket **226** via wire harness **224** to an isolation circuit **216**. Circuit **216** isolates a variety of input/output lines (I/O) **214** from I/O lines **222**. A pair of lines is dedicated for use as sensor lines (Sensor Line 1 **292** and Sensor Line 2 **294**) and are attached to contacts **288** and **290**, which are preferably, but not necessarily at the distal end **221** of socket **226.**

For simplicity of deployment we have designed circuit **202** to be identical to circuit **216** (ref. **Figures 2** and **3**) though this feature is not a required aspect of this invention. Although we indicate seven sets of corresponding electrical contacts associated respectively with plug **212** and socket **226**, it is obvious that the number of sets of contacts applicable to this application can be any reasonable number greater than two, and the depiction of seven contacts is merely arbitrary and illustrative of the principles to be employed.

Figure 2 is a more detailed schematic diagram of the isolation circuit **202** in respect of the plug contacts **211**, as shown in **Figure 1**. The I/O lines comprise a Power Line **235** monitored by Current Sensor **242** that controls Power Switch **244**, Digital Lines **233**, **234** controlled by Digital Switches **246**, an Unswitched Line **248**, a Ground Line **250**, two Sensor Lines **280** and **282**

controlled by Sensor Circuit **256,** and Timer Circuit **258**, the Timer **258** providing an Interrupt Line **260** to control Power Switch **244** and Digital Switches **246**. A diode **276** is carried by Sensor Lines **280** and **282**.

Figure 3 is a more detailed schematic diagram of the isolation circuit **216** in respect of the socket contacts **213**, as shown in **Figure 1**. The I/O lines comprise a Power Line **236** monitored by Current Sensor **241** that controls Power Switch **243**, Digital Lines **231, 232** controlled by Digital Switches **245,** an Unswitched Line **247**, a Ground Line **249**, two Sensor Lines **292** and **294** controlled by a Sensor Circuit **257** and Timer Circuit **259**, the Timer **259** providing an Interrupt Line **261** to control Power Switch **243** and Digital Switches **245.** A diode **302** is carried by Sensor Lines **292** and **294**.

Figure 4 shows plug Sensor Circuit Detection means **263** and socket Sensor Circuit Detection means **264** shown generally in **Figures 2 and 3** respectively and how the Sensor Lines **292**, **294** and **280, 282** are activated only by the full engagement of the plug **212** and socket **226**. A positive potential +V on the plug sensor circuit side **235** is connected to a resistor R1 (**272**), then to a forward-biased diode **274**, then to diode **276** that acts to block this current, and finally to another resistor R2 (**278**) that is grounded **250**. Sensor Line 1 **(280)** from the junction of **274** and **276** is connected to plug contact **284**. Sensor Line 2 **(282)** from the junction of **276** and **278** is connected to plug contact **286** and also to the plug Sensor Circuit input **256**. Similarly, a positive potential +V on the socket circuit side **236** is connected to a resistor R1 (**298**), then to a forward biased diode **300,** then to a diode **302** that acts to block this current, and finally to another resistor R2 (**304**) which is grounded **250**. Sensor Line 1 **(292)** from

the junction of **300** and **302** is connected to socket contact **290**. Sensor Line 2 (**294**) from the junction **302** and **304** is connected to socket contact **288** and also to the socket Sensor Circuit input **257**.

It will be noted that the sensor lines **292**, **294** on the socket Sensor Circuit Detection means **264** are crossed with respect to socket connections **288** and **290**. Apart from this detail the full circuits and wiring for both plug and socket Sensor Circuits **256, 257** are identical. The plug-side and socket-side Sensor Circuit Detection means **263**, **264** may alternatively be arranged as shown in **Figure 5**, wherein Sensor Lines **280, 282** are crossed with respect to plug connections **284** and **286.**

We proceed by explaining various embodiments in order to clarify how the system determines when the plug/socket combination has achieved full engagement.

EMBODIMENT 1

Figure 6 denotes an arrangement where active powered electronic circuits are incorporated only on the plug side, and furthermore that electronic access to the plug side circuits does not require socket side isolation circuitry because the socket side is essentially passive. For illustrative purposes we set the power line +V at 15 volts, resistor R1 (**272**) is 50,000 ohms and resistor R2 (**278**) is 100,000 ohms.

As may be seen with reference to **Figure 6**, the determination of the full engagement of plug **212** and socket **216** (whereby electronic circuitry which requires isolation occurs on the plug side) is achieved as follows. Current from supply line **235** flows through resistor R1 (**272**), through forward-biased diode **274** and is blocked from the plug sensor circuit output by diode **276**. A current pathway is available across the plug/socket junctions **284** and **288**, through diode **302** that now acts as a sensor activation element by passing current back through plug/socket junctions **290** and **286**, and finally through resistor R2 (**278**) to Ground **250**. The potential across resistor R2 (**278**) with respect to Ground **250** is sensed by the plug Sensor Circuit **256** to be approximately 2/3 times 15V (set by the potential divider R1/R2 i.e. ~10V). The threshold voltage necessary to activate the plug Sensor Circuit (**256**) could be set at 6 or 7 volts, greater than typical logic levels of 5V. Thus the activation voltage of ~10V is comfortably greater than the threshold, and false activations are minimized. Diode **302** is forward biased because of the crossed sensor lines **292** and **294** on the socket side. Were this not the case the required voltage potential at the plug Sensor Circuit **256** would not be available because no current could flow through resistor R2 (**278**), causing the appropriate activating voltage to be absent. Thus only when plug **212** and socket **216** are fully engaged is the plug Sensor Circuit **256** activated, and the switched lines forming part of the I/O bus **200** are then electrically connected to the I/O bus **208**. Hence the switched (and also the unswitched) lines are correctly available at the socket via the fully engaged plug.

It will be obvious to one reasonably skilled in the art that there should be no electrical circuits associated with socket **226** such as Digital Switches **245** that are in electrical communication with any of the non-sensor contacts **213** that would be electrically mistaken for the action of diode **302**, so as to otherwise initiate a "triggering" of the Power Switch **244**. To further guard against such a possibility, in a preferred embodiment of this aspect of the invention the output of Sensor Circuit **256** in respect of the plug sensor circuitry is passed through timer **258** (ref. **Figure 2**). The function of Timer Circuit **258** is to delay activation of Interrupt Line **260** controlling Power Switch **244** and Digital Switches **246** until the full engagement of plug **212** and socket **226** can be reasonably expected (typically one to two minutes).

The only significant requirements on the passive socket side is a diode **302** that is forward biased by crossed sensor lines **292, 294** in order that the Sensor Circuit **256** is correctly activated.

EMBODIMENT 2

The complementary circuit to Embodiment 1 is depicted in **Figure 7** and denotes an arrangement where active powered electronic circuits are incorporated only on the socket side, and furthermore that electronic access to the socket side circuits does not require plug side isolation circuitry because the plug side is essentially passive. For illustrative purposes we set the power line +V at 15 volts, resistor R1 (**298**) is 50,000 ohms and resistor R2 (**304**) is 100,000 ohms.

As may be seen with reference to **Figure 7**, the determination of the full engagement of plug **212** and socket **216** (whereby electronic circuitry which requires isolation occurs on the plug side) is achieved as follows. Current from supply line **236** flows through resistor R1 (**298**), through forward-biased diode **300** and is blocked from the plug sensor circuit output by diode **302**. A current pathway is available across the plug/socket junctions **290** and **286**, through diode **276** that now acts as a sensor activation element by passing current back through plug/socket junctions **284** and **288**, and finally through resistor R2 (**304**) to Ground **250**. The potential across resistor R2 (**304**) with respect to Ground **250** is sensed by the socket Sensor Circuit **257** to be approximately 2/3 times 15V (set by the potential divider R1/R2 i.e. ~10V). The threshold voltage necessary to activate the socket Sensor Circuit (**257**) could be set at 6 or 7 volts, greater than typical logic levels of 5V. Thus the activation voltage of ~10V is comfortably greater than the threshold, and false activations are minimized. Diode **276** is forward biased because of the crossed Sensor Lines **292** and **294** on the socket side. Were this not the case the required voltage potential at the socket Sensor Circuit **257** would not be available because no current could flow through resistor R2 (**304**), causing the appropriate activating voltage to be absent. Thus only when plug **212** and socket **216** are fully engaged is the socket Sensor Circuit **257** activated, and the switched lines forming part of the I/O bus **214** are then electrically connected to the I/O bus **222**. Hence the switched (and also the unswitched) lines are correctly available at the socket via the fully engaged plug.

It will be obvious to one reasonably skilled in the art that there should be no electrical circuits associated with plug **216** such as Digital Switches **246** that are in electrical communication with any of the non-sensor contacts **213** that would be electrically mistaken for the action of diode **276**, so as to otherwise initiate a "triggering" of the Power Switch **243**. To further guard against such a possibility, in a preferred embodiment of this aspect of the invention the output of Sensor Circuit **257** in respect of the socket sensor circuitry is passed through timer **259** (ref. **Figure 3**). The function of Timer Circuit **257** is to delay activation of Interrupt Line **261** controlling Power Switch **243** and Digital Switches **245** until the full engagement of plug **212** and socket **226** can be reasonably expected (typically one to two minutes).

The only significant requirements on the passive plug side is a diode **276** that is forward biased by crossed sensor lines **292, 294** in order that the Sensor Circuit **257** is correctly activated.

EMBODIMENT 3

The discussion of Embodiment 1 and Embodiment 2 above now makes the complete understanding of Embodiment 3 as exemplified by either **Figure 4** or **Figure 5** straightforward. Both plug sensor circuit **236** and socket sensor circuits **264** are powered independently by +V(plug) **235** and +V(socket) **236** lines. Taking **Figure 4** for example, the voltage level output to Sensor Circuit **256** (plug) is available via either of two routes:

a) current from line **235** via resistor R1 (**272**) and diode **274** passes along Sensor Line 1 (**280**) to contacts **284** and **288,** then via Sensor Line 2 (**294**) through diode **302**, Sensor Line 1 (**292**), contacts **290** and **286**, Sensor Line 2 (**282**) and through resistor R2 (**278**) to Ground **250**. The potential at the junction of R2 (**278**) and Sensor Line 2 (**282**) with respect to Ground **250** is now available to activate the plug Sensor Circuit **256**; or

b) current from line **236** through resistor R1 (**298**) and diode **300** passes along Sensor Line 1 (**292**), through contacts **290** and **286,** then via Sensor Line 2 (**282**) through resistor R2 (**278**) to Ground **250**. The potential at the junction of R2 (**278**) and Sensor Line 2 (**282**) with respect to Ground **250** is now available to activate the plug Sensor Circuit **256.**

The choice of routes a) or b) is determined solely by whether +V(plug) **235** is greater than +V(socket) **236** by more than one diode drop (typically 0.6V). In either case the significant issue is that the plug Sensor Circuit **256** is activated by an adequate +V(socket) **236** potential or by the presence of diode **302** – both are associated only with the full engagement of the plug and socket, and either will suffice.

Likewise, the voltage level output to Sensor Circuit **257** (socket) is similarly available via either of two routes:

c) current from line **236** via resistor R1 (**298**) and diode **300** passes along Sensor Line 1 (**292**) to contacts **290** and **286,** then via Sensor Line 2 (**282**)

through diode **276**, Sensor Line 1 (**280**), contacts **284** and **288**, Sensor Line 2 (**294**) and through resistor R2 (**304**) to Ground **250**. The potential at the junction of R2 (**304**) and Sensor Line 2 (**294**) with respect to Ground **250** is now available to activate the plug Sensor Circuit **257**; or

d) current from line **235** through resistor R1 (**272**) and diode **274** passes along Sensor Line 1 (**280**), through contacts **284** and **288,** then via Sensor Line 2 (**294**) through resistor R2 (**304**) to Ground **250**. The potential at the junction of R2 (**304**) and Sensor Line 2 (**294**) with respect to Ground **250** is now available to activate the plug Sensor Circuit **257**.

Again, the choice of routes c) or d) is determined solely by whether +V(socket) **236** is greater than +V(plug) **235** by more than one diode drop (typically 0.6V). In either case the significant issue is that the socket Sensor Circuit **257** is activated by an adequate +V(plug) **235** potential or by the presence of diode **276** – both are associated with the full engagement of the plug and socket, and either will suffice.

Diodes **274** and **300** ensure that there can be no unintended reverse current flow into their associated power supply from the power supply at higher potential on the other side of the plug/socket.

This embodiment illustrates usefulness of the symmetry of the circuit operations attached to either plug or socket – fabrication of the switching circuits is simplified in that both assemblies can be identical. The only

necessary modification is that the lines must be crossed between contacts **288**, **290** and Sensor Lines **292** and **294** (as shown in **Figure 4**), or equally between contacts **284**, **286** and Sensor Lines **280** and **282** (as shown in **Figure 5**). In these embodiments, when plug and socket are fully engaged, **Figures 2** and **3** indicate that the Power Switch lines (**235**, **236**), Digital Switch lines (**233**, **234**, **231**, **232**), the Unswitched Lines, Ground Lines and Sensor Lines are all connected appropriately. This enables power to flow as required from plug to socket or vice versa, digital information to flow as required from plug to socket or vice versa, etc.

Our invention does not limit us to a 'one-to-one' line connection correspondence, however. The obvious inclusion of more contacts in plug **212** and socket **226** would enable the independence of the information or power carrying lines. The necessary and sufficient feature for determining full engagement is that plug Sensor Line 1 (**280**) connects to socket Sensor Line 2 (**294**) and plug Sensor Line 2 (**282**) connects to socket Sensor Line 1 (**292**) when diode **276** and/or diode **302** (for example) are chosen as the engagement sensing devices. Specific wiring connections through a representative plug and socket pair is depicted in **Figure 8**. In particular the Sensor Line crossed wiring (**282** to **292**, **280** to **294**) is evident.

Importantly, with respect to each of the embodiments shown in **Figures 2** and **3**, the present invention is not limited to a sensory circuit using only a simple diode as a sensing means. In particular, it is possible and is contemplated within the scope of the present invention to replace each diode **276** and/or **302**

by other electrical circuitry, including current direction-limiting circuitry, so as to permit the sensor circuit to produce a particular electronic signal when specifically sensed at full engagement of the plug **212** and socket **226.** The present invention is not to be limited to circuitry implementing only diodes **276** and **302**.